OBSERVATION OF RIPARIAN VEGETATION IN WESTERN NAMIBIA BY USING NDVI AND NDWI DERIVED FROM SPOT-VEGETATION

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ABSTRACT Ephemeral rivers in western Namibia are unique entities that support both natural vegetation and human activities. This paper presents an approach for observing riparian vegetation along them synoptically using remotely sensed datasets, derived from a satellite borne sensor named SPOT-VEGETATION. The most commonly used vegetation index, the Normalized Difference Vegetation Index (NDVI), certainly delineates the overall distribution of vegetation, but not without errors. A vegetation index that was designed as a supplement for NDVI, the Normalized Difference Water Index (NDWI), showed some interesting features, but again, with faults. By synthesizing the two indices, the scarce and sparse vegetation in coastal deserts and the relatively dense vegetation in inland highlands could be efficiently observed. Furthermore, by introducing a flow accumulation model produced from a digital elevation model (DEM), it became possible to observe such riparian vegetation quantitatively and systematically.

Key Words: Riparian vegetation; Ephemeral rivers; Flow accumulation model; Namibia; Normalized Difference Vegetation Index; Normalized Difference Water Index; SPOT-VEGETATION.

INTRODUCTION

Ephemeral rivers in western Namibia are at the center of several natural and social scientific contexts. Geographically, they stretch westward from areas of relatively high rainfall, ranging between 300 and 600 mm per year (Jacobson *et al.*, 1995), to drier areas of 100 mm per year or less (Jacobson *et al.*, 2000). They may only fill up with water seasonally, or once every few (up to ten) years. Ecologically, they support riparian vegetation and provide intermittent water sources for fauna. Economically, they are critical resources for both agriculture and tourism development. In this arid region, water is of great importance, and hence, observation of ephemeral rivers and riparian vegetation along them is an important task for many communities.

OBJECTIVE OF STUDY

There are two ways to carry out observations of ephemeral rivers and riparian vegetation along them. One involves field observation, and the other synoptic observation; both have advantages and disadvantages. The objective of this study was to lay a foundation for synoptic observations of ephemeral rivers and their catchments by using datasets derived from a satellite sensor and a digital elevation model. This attempt could be of significance. The synoptic observation could function as a matrix to weave a number of individual field observations, which could in turn lead to a better understanding of the rivers and their catchments in the future.

STUDY AREA AND DATASETS

This study focuses on the ten catchments in western Namibia. Their sizes and shapes vary. They share, however, certain common features. The ephemeral rivers in them originate from inland mountains. Courses of the rivers towards the Atlantic Ocean correspond to the steep climatic gradients mentioned earlier: There is a contrast between the tributaries in the upper streams that are often moist and the mainstreams in the coastal deserts that are almost lastingly dry with very rare punctuations.

To observe the area synoptically, SPOT-VEGETATION (VGT) datasets having 1 km per pixel spatial resolution were used in this study. The particular type of the datasets used was called VGT-S10. It is a synthesized dataset in which cloud free pixels are compiled from scenes of the area of interest acquired over ten days. The synthesized data sets, S-10, consisted of four spectral bands and pre-processed Normalized Difference Vegetation Index (NDVI). In the preparatory stage, 36 sequential S-10 datasets from April 1998 to March 1999 were acquired. From these scenes, the rectangular area containing Namibia was cropped. GTOPO 30 Digital Elevation Model (DEM) having 1 km spatial resolution was also used in this study. Two tiles of the global DEM were combined together, and the relevant area was extracted.

PARAMETERS

Two parameters were used in this study for characterizations of vegetation along the ephemeral rivers and in their catchments. One of these was NDVI. This parameter indicates vigor of vegetation by taking advantage of its spectral characteristics: While vegetation absorbs electromagnetic radiation in the visible region, it reflects that in the near-infrared region; and, the absorption and reflectance can be measured and the difference calculated.

An important point to note is that although they are called ‘rivers’, ephemeral rivers are essentially exposed riverbeds. This means that what to observe is not actual water, but the results of occasional water. In this context, riparian vegetation is a relevant medium.

A further consideration was required in this study. As the rivers and their catchments were in an arid area, sole reliance on NDVI for observation of vegetation might not be appropriate. To ameliorate this uncertainty, another parameter, the Normalized Difference Water Index (NDWI) was introduced to this study. This parameter indicates the moisture content of vegetation (Gao, 1996). In other words, it is better used as a supplement to NDVI (*ibid.*). This parameter was not readily available, and therefore computed from the spectral bands of SPOT-VEGETATION as Xiao *et al.* (2002) did in a previous study. Later in this paper, what these two parameters indicated are examined first, and an attempt to combine them together is made.

EXTRACTION OF WATERSHEDS FROM DIGITAL ELEVATION MODEL

A series of terrain analysis procedures were applied to the prepared DEM. Two raster layers were produced from this phase. One of these was a flow accumulation layer, indicating how water flows down the terrain. The other layer indicated watersheds, more specifically, sub-watersheds that comprise the catchments defined by Jacobson *et al*., (1995). The small watersheds were combined together until the outline of the catchments (*ibid.*) appeared. After this integration process, the catchments were vectorized. The original elevation model prepared for this study and the consequent datasets were used in conjunction with the two parameters explained earlier.

SEASONAL AMPLITUDES OF VGT-NDVI

Vegetation vigor for one year was observed and a number of useful points were found. The first operation was a further maximization of the cropped S-10 NDVI dataset. This transformed the 10-day NDVI MVC (maximum value composite) dataset consisting of 36 images into a monthly NDVI MVC dataset consisting of 12 images.

The second operation was an unsupervised classification procedure. The ISODATA algorithm (Tou & Gonzalez, 1974) was used for the monthly VGT-NDVI MVC dataset to group pixels having same patterns of seasonal fluctuation. Fig. 1 shows the results, and Fig. 2 shows the monthly mean VGT-NDVI of each class area. These should not be taken as a definitive segmentation of vegetation in the area. While there was a likely correlation between the output of our classification procedure and various aspects of vegetation, such as species, formation, or density, the purpose of the operation was to produce a probe to further the analysis on the riparian vegetation. The number of classes, nine, was determined solely for visualization purposes.

The results of the classification operation provided a number of useful points. Firstly, the concordance between the spatial distribution of the classes (Fig. 1) and their chronological fluctuations (Fig. 2) is remarkable. Amplitudes of VGT-NDVI values of upstream areas are generally larger than those of downstream areas. There is a gradation of VGT-NDVI between inland highlands and coastal deserts. Secondly, in relation to the first point, durations that VGT-NDVI

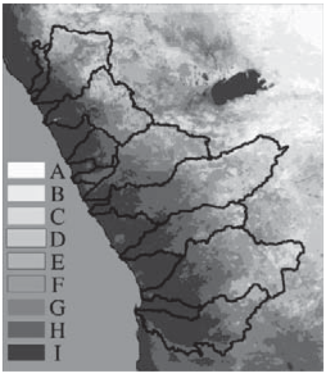

Fig. 1. Nine classes resulted from the ISODATA classification.

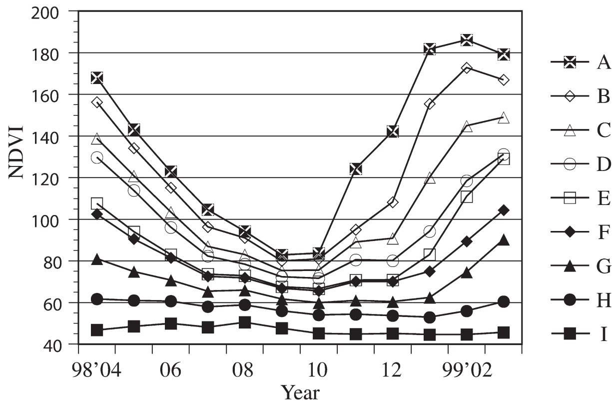

Fig. 2. Monthly changes of mean VGT-NDVI of the classes.

Fig. 3. The Namib Sand Sea.

Fig. 4. Coastal Desert.

values of the upstream areas stay low are shorter than those of the downstream areas. Thirdly, and possibly most importantly in the context of this study, the Namib Sand Sea in the south of the Kuiseb catchment was in the class H area. The sand sea shown as Fig. 3 is as scarcely vegetated as the class I areas of which example is shown as Fig. 4. This point implies delimitation of sole reliance on VGT-NDVI in observations of such arid areas.

SEASONAL AMPLITUDES OF VGT-NDWI

It is of considerable interest to examine fluctuations of VGT-NDWI. Fig. 5 shows the monthly mean VGT-NDWI in areas defined by the ISODATA classification operation applied to the sequential VGT-NDVI dataset. When comparing Fig. 2 and 5, the following three points should be noted. Firstly, similar to the behavior of the monthly VGT-NDVI, VGT-NDWI of the upstream areas had larger amplitudes and stayed low for a shorter duration than in the downstream areas. Secondly, unlike those of the VGT-NDVI, VGT-NDWI of the upstream areas became even lower than that of the downstream areas and the Etosha Pan

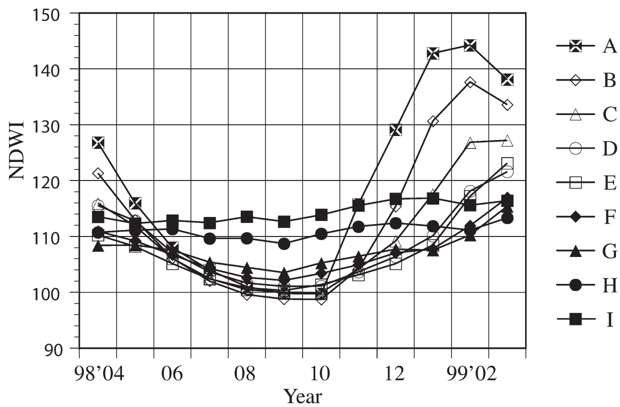

Fig. 5. Monthly changes of mean VGT-NDWI of the classes.

from June to November. Thirdly, and most strikingly, coastal desert areas (Fig. 3 & 4) and the Etosha Pan retained a certain level of VGT-NDWI throughout the one-year period.

The similarities and differences between fluctuations of VGT-NDVI and VGT-NDWI values, as well as being interesting issues in themselves, provide useful clues for further data processing in this study. Probable explanations for the unexpected behaviors of the VGT-NDWI are that:

1) NDWI was designed originally to measure the moisture of vegetation, but not of soil;
2) The coastal desert areas and the Etosha Pan coincidentally had spectral characteristics similar to moderately moist vegetation; and
3) VGT-NDWI of scarce or dense vegetation in inland areas exceeded the 'quasi moisture' of soil background as the dry season ended and the rainy season started.

This explains the sequential turns depicted in Fig. 5; it also implies delimitation of sole reliance on VGT-NDWI.

SYNTHESIS OF THE TWO PARAMETERS

The two parameters having been examined so far are usefully indicative of vegetation conditions in the catchments but not entirely free from error. It is, then, sensible to combine them together. A gambit to find a way to synthesize the two parameters is to produce a two dimensional feature space by using them as the axes. The two graphs, Fig. 2 and 5, can be combined in such a feature space. The seasonal trajectories of the classes, which are determined by VGT-NDVI and VGT-NDWI, can be represented as a scatter plot shown in Fig. 6.

This graphical representation of vegetation conditions of the area leads to a number of noteworthy points. Most notably, it implies that:

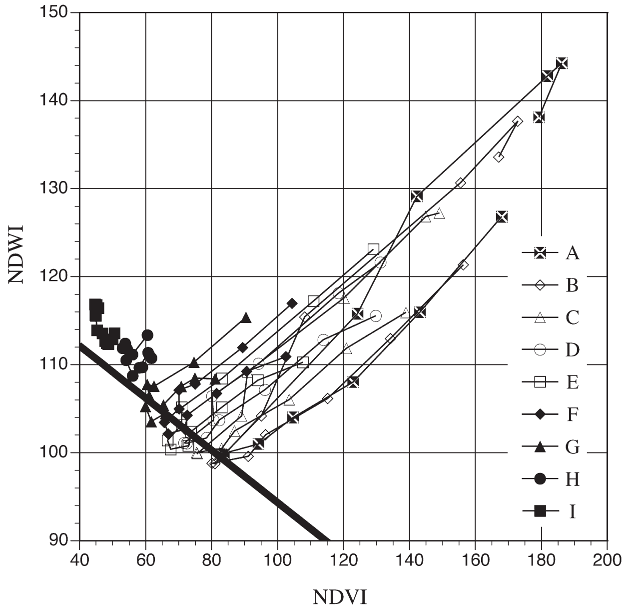

Fig. 6. Scatterline plot.
Monthly mean VGT-NDVI (X) and VGT-NDWI (Y) values of the classes.

1) The lowest (i.e. bottom left) coordinates of all seasonal trajectories were from September VGT-NDVI and VGT-NDWI images, and aligned along a diagonally downward line from left to right in the feature space; and
2) Amplitudes of trajectories, the distance between the bottom left coordinate and the top right coordinate, for coastal areas were smaller than those for inland highlands.

In short, the amplitudes of the trajectories were inversely proportional to the coordinate values determined by the driest month, September.

A straightforward way to take advantage of the above points to synthesize the two parameters was to calculate the magnitude of seasonal trajectory that each pixel had. This could be an appropriate indicator for what the Namibian ephemeral rivers go through and how they function. An image as a compilation of such pixels was produced through the following image arithmetic:

$$Amplitude = \sqrt{(NDVI_2 - NDVI_1)^2 + (NDWI_2 - NDWI_1)^2}$$

where $NDVI_1$, $NDVI_2$, $NDWI_1$ and $NDWI_2$ were the VGT-NDVI and VGT-NDWI images in September 1998 and March 1999 respectively. The resultant two-dimensional amplitudal image, shown in Fig. 7, indicates the distances between coordinates determined by the two parameters in September 1998 and those by the parameters in March 1999. This approach may be comparable to that of Malila (1980), Kajiwara and Tateishi (1990), and Lambin and Strahler (1994a, b), whereby the researchers carried out ‘change vector analysis.’ A difference

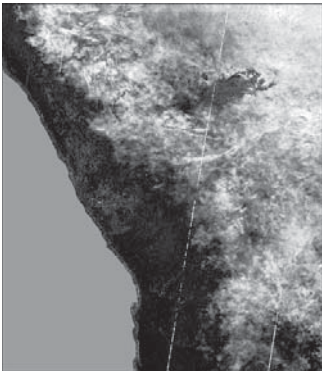

Fig. 7. Two dimensional amplitudal image.

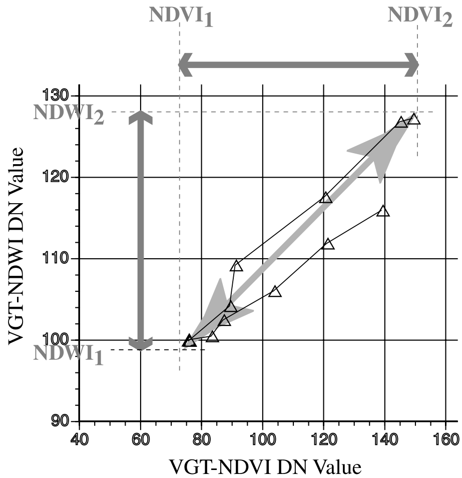

Fig. 8. Scatterline plot.
Two-dimensional amplitude — VGT-NDVI (X) and VGT-NDWI (Y)

between them and the above operation is that while two spectral bands were used in the formers, two indices were used in the latter.

The two-dimensional amplitudal image had a distinctive characteristic as compared to the VGT-NDVI and VGT-NDWI. The length of the two-dimensional amplitudal vector was longer than either of the two parameters, as shown in Fig. 8. This characteristic could be useful in observations of vegetation conditions along ephemeral rivers and in their catchments.

OBSERVATIONS OF RIPARIAN VEGETATION

The approach having been explained so far produced a matrix for spatiotemporal analyses of the Namibian riparian vegetation. The potential was more effectively exploited through introduction of the DEM. The first step in utilization of the DEM was production of a flow accumulation model. A DEM consists of pixels indicating altitude of corresponding areas. It is, then, possible to estimate how surface waters as streams converge and rivers run through valleys and plains if a set of relevant algorithms are applied to the DEM. This operation was carried out and the resultant flow accumulation model is shown in Fig. 9. For better visual presentation, darkness/lightness of the mainstreams are differentiated from that of the tributaries.

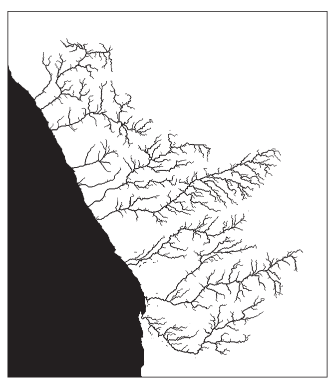

Fig. 9. Flow accumulation model.

The flow accumulation model is hypothetical. It is not definitive in the sense that the ground is

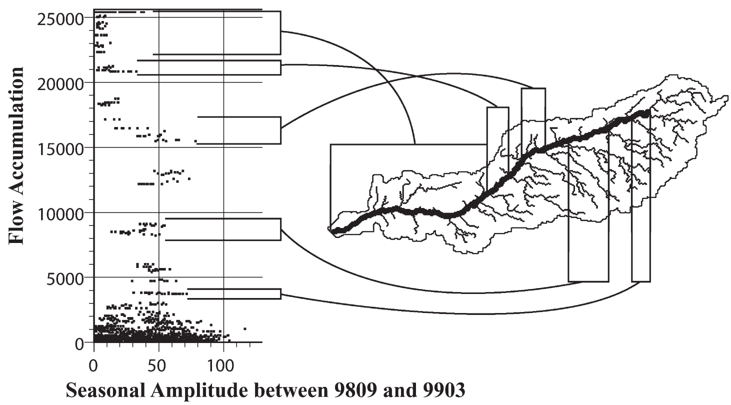

Fig. 10. Two-dimensional seasonal amplitude of the Ugab River.

rarely impermeable, precipitation tends to be uneven over a large area, and there is continuous evaporation from the surface of rivers and streams. In reality, the amount of water that is held by rivers and streams is highly likely to be different from that indicated by a flow accumulation model. It is, however, still a useful summary of catchments and a practical method for delineating probable watercourses. In the case of western Namibia, the model could be remarkably useful when determining how precious rainfalls are transformed into water flows and how they influence vegetation.

The second step was a modification of the flow accumulation model. The model indicated how much water was accumulated, theoretically, at each pixel. By imposing a threshold, the water courses could be more clearly expressed. In this study, the threshold was set to 100. This value produced lines through which water runs, accumulated from areas larger than 100 sq·km, and it omitted minor tributaries. After this operation, the flow accumulation values of the rivers were divided by 100 just to fit the range of the value to a relevant scale for calculation.

A series of scatter plot were produced by combining the modified flow accumulation model and the two dimensional amplitudal image. More concretely, river specific feature spaces were produced by assigning the former to the Y axis and the latter to the X axis. A scatter plot made for the Ugab catchment by using this method is shown as Fig. 10. This diagram also indicates which range on the Y-axis corresponds to which part of the Ugab River. Tributaries of the river were distributed over both coastal desert and vegetated highlands: They are represented as an agglomeration, having a wide range of X values and low Y values. As the flow accumulation value of the river increases (i.e., above the region of the agglomeration at the bottom), the X value decreases slightly, and increases again. In the coastal desert, the X value becomes extremely low, but shows a sudden increase at the Y value 21000. This increase was highly likely due to water inflow from nearby mountains.

It is also possible to produce sequential scatter plots to observe the

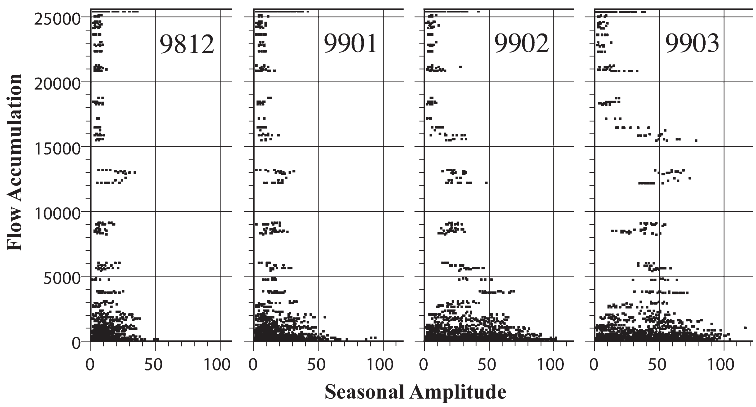

Fig. 11. Seasonal fluctuations of two-dimensional amplitudal value for the Ugab River.

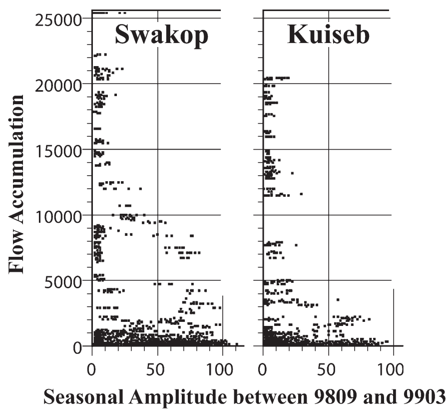

Fig. 12. Characterization of the drainage networks: Swakop and Kuiseb.

seasonality of the riparian vegetation. In addition to the data in Fig. 10, which features the difference between September 1998 and March 1999, differences between the former and other months could be observed as shown in Fig. 11. It is remarkable that the part of the river of which the Y value range is between 15000 and 18000 showed a dramatic increase in the X value in the period between February and March 1999. Such a feature could be useful for further research and field observation.

The same approach can be used for comparison of vegetation conditions along the ephemeral rivers. For example, Fig. 12 shows a comparison of the Swakop and Kuiseb Rivers. The diagram for the Swakop River features a ring-like shape. The shape was formed because the downstream of the Khan River was without much vegetation and the upstream of the Swakop River had relatively dense vegetation with the same Y value, and the two rivers joined in the coastal desert. Without the part of the upstream Swakop River, the two diagrams in Fig. 12 would look more similar. The diagram of the Kuiseb River has its own uniqueness; it has a few stray vegetated dots in the Y value range between 5000 and 15000. These were highly likely to be riparian vegetation that would look like oases on the ground. Both diagrams show increases of the X value at the river mouths (i.e., the top ends). These were probably due to vegetation in the two large coastal cities: Swakopmund at the mouth of the Swakop River, and Walvis Bay at the mouth of the Kuiseb River.

CONCLUSIONS

The approach explained in this study has demonstrated a way to observe synoptically vegetation along the ephemeral rivers and in their catchments in Western Namibia. It remains only an approach at present. It could be, however, developed further to function as a foundation for holistic comprehension of arid/semi-arid environments that would set individual field observations in relevant contexts. As development issues, such as the constructions of dams for agricultural water management or the expansion of the tourism industry, grow in importance, western Namibia needs a strong foundation for synoptic environmental comprehension. Future research scopes held from the achievements of this study comprise introduction of higher spatial resolution data sets for observations of areas of special interests and hyper spectral data sets for further investigation of the relationship between the rivers and vegetation covers.

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